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Sustainable Cementitious Composites Reinforced with Kenaf Fibers: Performance Insights from a Concise Review

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Abstract: The construction industry faces increasing pressure to adopt sustainable materials that minimize environmental impact while maintaining structural performance. Natural fibers, particularly kenaf, have gained growing interest as eco-friendly alternatives in cementitious composites due to their biodegradability, cost-effectiveness, and favourable mechanical properties. This review paper aims to examine current research on kenaf fiber-reinforced cement composites, with a specific focus on their mechanical performance and durability under construction practices. By critically analysing published studies, this review highlights the effects of kenaf fiber incorporation on compressive strength, tensile strength, flexural behaviour, and resistance to cracking, degradation and, so on. The methodology employed involves a systematic collection and evaluation of peer-reviewed journal articles, conference proceedings, and other academic resources from various researchers, providing a comprehensive understanding of the key trends, experimental techniques, and outcomes reported in the field. Key findings reveal that kenaf fibers can significantly enhance the toughness and ductility of cementitious composites, although challenges such as fiber dispersion, interfacial bonding, and water absorption require optimized treatment methods and mix designs. The implications of these findings support the potential of kenaf fiber-reinforced cement composites as viable materials for green construction, especially in regions with abundant natural fiber resources. Overall, this review contributes to advancing sustainable construction materials by synthesizing the current knowledge and promoting further research into the practical integration of kenaf fibers in cement-based systems.

Keywords: *natural fiber, plant fiber, kenaf fiber, cement composites, mechanical properties*

1.0 INTRODUCTION: OVERVIEW OF NATURAL FIBERS

The contemporary century's swift advancements in several economic areas have led to a rise in the use of energy and resources, particularly in the construction sector. As a result, more kinds of waste are produced during the manufacture of various goods, including waste from agriculture and construction, which poses major health risks, complicates their disposal, and contributes to environmental concerns. Therefore, transforming them into recyclable or reusable materials and utilizing them for any purpose will promote sustainable development. One promising area of innovation is the promotion of natural fiber-reinforced cement composites. These materials offer a sustainable alternative to traditional composites by incorporating renewable, biodegradable fibers, reducing the reliance on synthetic materials and lowering the overall carbon footprint of construction projects. According to numerous kinds of literature in the entire world, many varieties of waste are practically used as new products or added as admixtures, so that natural sources are utilized more efficiently and the environment is protected from waste deposits. On the other hand, the advantages of waste materials are pronounced in the aspects of reduction in environmental burden and waste management cost.

The growing interest in energy-efficient and environmentally friendly construction materials has driven the development of cement composites reinforced with various natural fibers. Natural fibers such as jute, hemp, flax, sisal, and bamboo, are abundant, renewable, and biodegradable. These fibers have been used traditionally in various industries due to their favorable mechanical properties and environmental benefits. In the context of cement composites, natural fibers offer several advantages. According to Marfa et al. (2020), the benefits of using natural fibers such as biodegradability, renewability, low density, relatively high specific strength, reduced tool wear, and low cost have been well-documented in research articles. The consumption of natural fibers is also lower in carbon footprint, which means that the cultivation and processing of natural fibers typically require less energy compared to synthetic fibers, resulting in lower greenhouse gas emissions.

1.1 Synopsis of Plant Fibers in Cement Composites

Cementitious composites such as grout, mortar, and concrete play a central role as the most widely used building materials worldwide, particularly in infrastructure projects that demand high ductility and energy absorption including bridge decks, highway pavements, and industrial building floors. Cement composites represent a key innovation in the construction industry, combining the strength and versatility of cement with various reinforcing materials to improve performance and sustainability. These materials play an essential role in modern construction practices, offering solutions to challenges ranging from structural integrity to environmental impact. As known, cement is a fundamental building material, that serves as the backbone of construction due to its binding properties and ability to form durable structures. Derived primarily from limestone and clay, cement production has historically been associated with significant energy consumption and greenhouse gas emissions. As the construction industry faces growing pressure to adopt sustainable practices, innovations in cement composites have emerged as viable solutions to reduce environmental impact while fulfilling performance demands. However, cementitious composites typically exhibit low tensile strength, poor ductility, limited cracking resistance, and low energy absorption [Hedjazi & Castillo, 2020]. Additionally, internal micro-cracks are inherently present in cementitious composites, and their low tensile strength is attributed to the propagation of these cracks, which can lead to brittle failure of the material [Al-Ghazali et al., 2022]. In such cases, enhancing the stiffness of cementitious composites by adding fibers is effective in bridging cracks, transferring loads, and improving the distribution of micro-cracks. Fibers act as crack arresters, significantly enhancing the properties of cementitious composites [Al-Ghazali et al., 2022].

In terms of engineering properties, plant fiber-reinforced cement composites demonstrate superior mechanical performance compared to conventional cement materials. The incorporation of plant fibers such as jute, hemp, flax, sisal, and bamboo enhance the tensile strength, flexural strength, and impact resistance of cement composites. Numerous studies have reported significant improvements in the mechanical and physical properties of cementitious materials through the incorporation of plant fibers. For instance, fly ash-based geopolymer composites reinforced with pineapple fibers demonstrated enhanced mechanical performance, achieving a compressive strength of 41.5 MPa and a flexural strength of 9.2 MPa [Diego et al., 2022]. In contrast, similar composites without fiber reinforcement exhibited significantly lower values, with a compressive strength of 12 MPa and a flexural strength of 6 MPa [Zulfiati et al., 2019]. These fibers distribute the stresses more effectively within the cement matrix, which helps to arrest crack propagation and improve overall durability. The interfacial adhesion between the cement matrix and reinforcing fibers is crucial to the overall performance of the composite, as it governs effective stress transfer from the matrix to the fibers. Poor bonding at the interface can result in incomplete load transfer and fiber pull-out, thereby reducing the composite's mechanical strength [Ogunbode et al., 2017]. The enhanced mechanical properties of these composites make them suitable for a broad range of construction applications, including both structural and non-structural components. Moreover, plant fibers are considerably lighter than conventional reinforcing materials such as steel. For example, steel fibers have a density of approximately 7.5 g/cm^3, while plant fibers such as coir, jute, hemp, flax, and sisal typically range from 1.2 to 1.5 g/cm^3 [Pickering et al., 2016]. This indicates that plant fibers are about 5 to 6 times lighter than steel. This reduction in weight translates to lighter cement composites, which offer several practical advantages. Lighter materials are easier to transport and handle, reducing logistics and labor costs. Additionally, the use of lightweight composites can decrease the overall load on structures, potentially leading to savings in foundation and structural support costs. This advantage is especially beneficial in applications where weight is critical, such as high-rise buildings and prefabricated construction.

One of the most compelling advantages of plant fiber-reinforced cement composites is their sustainability. Plant fibers come from renewable sources that can be cultivated and harvested repeatedly. This renewability contrasts sharply with non-renewable synthetic fibers and metals. Furthermore, plant fibers are biodegradable, allowing them to decompose naturally without leaving harmful residues, thereby reducing long-term environmental impact. The production process of plant fibers typically requires less energy compared to the extraction and processing of synthetic fibers and metals. Consequently, the overall carbon footprint of plant fiber-reinforced cement composites is lower, contributing to a reduction in greenhouse gas emissions. Kenaf and hemp fiber bundles, as well as their mixtures, significantly enhance the tensile strength and Young's modulus of composites. Therefore, these composites are well-suited for applications requiring high tensile strength and stiffness but subjected to low impact stress, such as furniture, boarding, or holders for grinding discs. In contrast, cotton fibers impart high impact strength to composites but result in reduced tensile strength and stiffness. Such composites are well-suited for applications subjected to impact loading, including automotive interior components and safety helmets. Blending bast fibers with cotton combines the superior tensile strength of bast fibers with the excellent impact resistance of cotton. This synergy improves the overall performance of the composite, making it suitable for various applications such as automotive parts and luggage shells [Graupner et al., 2009]. Moreover, the automotive industry is successfully using composites reinforced with various plant fibers to replace components like interior panels and seat cushions, which were traditionally made from glass mat PMC or polymeric foams [Monteiro et al., 2009].

By incorporating these composites into construction projects, the industry can move closer to achieving sustainability goals and reducing its environmental impact. Besides that, plant fiber-reinforced cement composites offer excellent thermal and acoustic insulating properties. The fibrous structure of natural materials helps to trap air and reduce thermal conductivity, which can enhance the energy efficiency of buildings. Improved thermal insulation can lead to reduced heating and cooling costs, contributing to the overall sustainability of the structure. Similarly, plant fibers' acoustic properties can help dampen sound transmission, providing better noise insulation. This is particularly advantageous in residential and commercial buildings where noise reduction is a priority. Enhanced acoustic insulation contributes to the comfort and well-being of occupants, making these composites a desirable choice for various construction applications. Despite numerous sources of plant fiber around the world that can cooperate in a cement matrix, this paper was aimed at focusing on other plant fibers, known as kenaf fiber. This review aims to serve as a valuable reference for academicians, engineers, students, and others interested in utilizing this environmentally friendly material to enhance the performance of cement-based composites.

2.0 LITERATURE REVIEW OF KENAF FIBER

2.1 Structure and Properties

Kenaf fiber is derived from the kenaf plant, scientifically known as *Hibiscus cannabinus* L., a fast-growing fibrous plant belonging to the Malvaceae family, which also includes cotton and jute. Primarily grown in tropical and subtropical regions, kenaf has been widely studied for its potential across various industries due to its high strength, biodegradability, and sustainability. Kenaf originated in Africa, but India and China now produce more than 70 percent of the world's supply, making them the major sources of bast fiber [Sim & Nyam, 2021]. In Malaysia, kenaf was introduced in the early 1970s and was recognized as a potential renewable fibrous resource for industrial purposes by the late 1990s [Ching et al., 2021]. In line with this, the Malaysian government has recognized kenaf as a fiber crop with significant economic potential and established the National Kenaf and Tobacco Board to support the growth of the fiber industry.

The kenaf plant was chosen for its fast growth, high productivity relative to land use, exceptional photosynthesis rate, and suitability for cultivation in the Malaysian climate. Kenaf typically grows to a height of 3.7–5.5 meters, with a stem diameter ranging from 25 to 51 millimeters, and can be harvested within 4–5 months under suitable temperature, soil, and rainfall conditions [Ahmad et al., 2010]. Kenaf is also a biodegradable and environmentally friendly crop, exhibiting one of the highest CO_2 absorption rates among natural fibers [Esmaeilpourshirvani & Taghavighalesari, 2019]. Nishino et al. [2003] reported that kenaf exhibits low density, non-abrasiveness during processing, high specific mechanical properties, and biodegradability. In addition, Gnanasekaran and Ayyappan (2018) found that kenaf fiber possesses notable properties, including a high rate of carbon dioxide absorption from the air, efficient uptake of nitrogen and phosphorus from the soil, and easy recyclability. It has gained attention for its versatile fiber, which has applications in various industries due to its environmental benefits and functional properties. As the world seeks sustainable alternatives to traditional materials, kenaf fiber stands out as a promising solution.

Kenaf consists of two main fiber types, which is bast and core [Juliana et.al., 2018]. Bast fibers, found in the outer bark, are long, strong, and flexible, making them ideal for high-strength applications. Core fibers, found in the inner woody core, are shorter and less dense, ideal for lightweight, biodegradable building materials and absorbent products. Additionally, Ashori et al. [2006] studied the morphology and chemical characteristics of both core and bast fibers, with SEM images revealing that bast fibers are thin and long, while core fibers are wide and short.

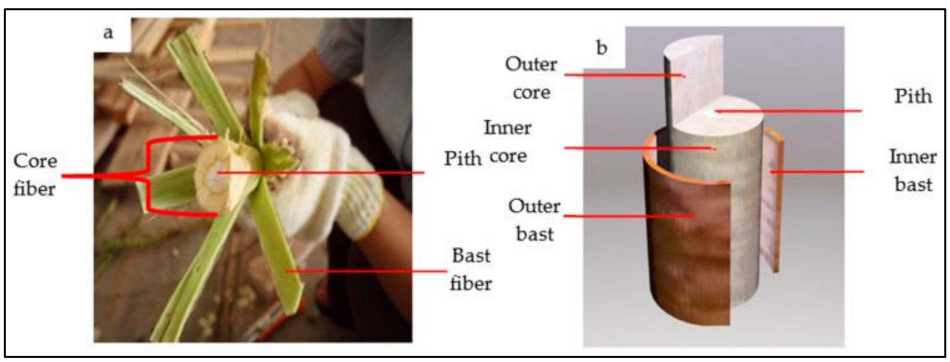

Figure 1: Kenaf outer and inner parts of the stem [Juliana et.al., 2012]

Moreover, kenaf bast fiber has been reported to possess superior flexural strength and excellent tensile strength, as shown in Table 1, making it a preferred material for a wide range of textile and non-woven products [Aji et al., 2009], including applications in construction materials. The findings from many researchers showed that the chemical composition of kenaf fiber especially high in cellulose, which are proofed as a binder agent in various products. Since cellulose is responsible for the strength and stiffness of the fiber, it's clear that bast fibers have higher strength compared to the core fibers, making them more advantageous as reinforcement material in cementitious composites [Al-Ghazali et.al., 2022].

Table 1: Comparison of the properties between kenaf bast and core [Ching et.al., 2021]

Properties	Unit	Bast Fiber	Core Fiber
Physical	Moisture Content (%)	73–75 (green stem)	
	Density (g/cm^3)	1.20–1.50	0.10–0.20
Chemical Composition	α-Cellulose (%)	55.0	49.0
	Holocellulose (%)	86.8	87.2
	Lignin (%)	14.7	19.2
	Ash Content (%)	5.4	1.9
	Extractives (%)	5.5	4.7
Mechanical	Tensile Strength (MPa)	295–1191	-
	Young's Modulus (GPa)	22–60	-
	Elongation (%)	1.6	-

2.2 Application of Kenaf Fiber in the Context of Industrial Relevance

Kenaf fiber has gained renewed attention in recent years due to increasing demand for sustainable, biodegradable, and high-performance materials. Its favorable mechanical properties, such as low density, high tensile strength, and significant cellulose content, make it highly suitable for diverse industrial applications, particularly in light of global environmental and circular economy goals. In the automotive sector, kenaf fiber is widely employed as a reinforcement in polymer composites used for interior components including door trims, dashboards, and insulation panels. Recent studies have demonstrated that kenaf-reinforced composites contribute to vehicle weight reduction while maintaining or improving mechanical performance and acoustic insulation, ultimately enhancing fuel efficiency and sustainability (Rahman et al., 2022; Hassan et al., 2023). The automotive industry continues to explore kenaf-based hybrids to meet stricter environmental regulations and reduce reliance on petroleum-based fibers.

The construction industry has also benefited from the incorporation of kenaf fiber into cementitious materials. Kenaf-enhanced concrete and mortar have shown improved crack resistance, thermal insulation, and durability compared to conventional materials. These improvements are particularly useful in green building applications and low-cost sustainable housing (Zainudin et al., 2021; Liew et al., 2023). Moreover, kenaf boards and insulation panels are increasingly being adopted for their energy-efficient and moisture-regulating properties. In the packaging industry, kenaf is gaining traction as a biodegradable reinforcement in bio-based plastics such as polylactic acid (PLA) and starch blends. Its inclusion has been shown to improve packaging stiffness and reduce degradation time, addressing the urgent need for more sustainable alternatives to conventional plastics (Tan et al., 2020; Ismail et al., 2024). The pulp and paper sector have also seen growth in kenaf utilization due to its high fiber yield and minimal chemical requirements during pulping. Kenaf-based paper products have demonstrated superior brightness and tear strength compared to wood pulp alternatives, contributing to reduced deforestation and processing costs (Chong et al., 2021). Emerging applications of kenaf fiber include biocomposites for aerospace, geotextiles for soil reinforcement, and fire-retardant panels. Recent advancements in surface treatment technologies and hybrid composite design have significantly improved the thermal and mechanical performance of kenaf-based materials, making them competitive with synthetic alternatives (Mahmood et al., 2025; Roslan et al., 2022). Collectively, these applications illustrate the increasing industrial relevance of kenaf fiber in line with sustainable material innovation and eco-conscious manufacturing strategies.

3.0 METHODOLOGICAL APPROACHES AND RESEARCH FINDINGS ON KENAF FIBER-REINFORCED CEMENTITIOUS COMPOSITES

Owing to the beneficial properties of kenaf fiber, this review aims to assess the impact of kenaf fiber reinforcement on the characteristics of cementitious composites, based on previous studies conducted by researchers worldwide. The performance of kenaf fiber-reinforced cement composites has been evaluated using various testing methods, including compressive strength, modulus of elasticity, flexural strength, drying shrinkage, slump test, and others. The main challenges of using kenaf fibers as reinforcement in cement composites include their high-water absorption, low durability, and poor fiber-matrix adhesion, which are attributed to the presence of hemicellulose, lignin, and pectin in their composition. This results in increased hydrophilicity, making kenaf fibers less compatible with hydrophobic matrices and weakening the bonding between particles in cement composites [Al-Ghazali et al., 2022]. For example, slump tests showed that kenaf-fiber cement composites exhibited lower workability compared to cementitious composites containing the same amount of horsehair fiber [Rahman et al., 2016]. Additionally, the performance of kenaf-fiber cement composites is strongly influenced by their mechanical properties, including compressive strength, flexural and tensile strength, impact resistance, and more. These characteristics are crucial for evaluating the capability and durability of the composites under various loads, especially under critical and severe conditions relevant to engineering performance. Abirami et al. [2020] incorporated 0.25 to 1 percent of kenaf and sisal fibers into cement-based composites. Their findings revealed that composites reinforced with 1 percent of either sisal or kenaf fibers exhibited the highest mechanical properties compared to those with lower fiber content. Despite this, the research by Beddu et al. [2021] found that the performance of cementitious composites containing 0.1 to 0.3 percent kenaf fiber has a higher compressive strength than the composites containing polypropylene fibers. Undeniably, the tensile and flexural strength of the fiber is also an important criterion to take into consideration if the fiber is planning to be used as reinforced fiber in cementitious composites. The tensile strength is influenced by many factors such as fiber content in cementitious composites. A study by Ishak et al. [2010] compared the tensile strength of unsaturated polyester composites reinforced with short kenaf bast and core fibers at varying fiber weight fractions. The results showed that the optimum fiber content for achieving the highest tensile strength was 20 percent. Although numerous studies have examined the mechanical properties of kenaf-fiber cement composites, there are noticeably fewer investigations focused on their durability properties. Babatunde et al. [2018] observed that adding 0.5 percent kenaf fiber significantly reduced the drying shrinkage of concrete, attributed to the fiber's ability to retain moisture. Shrinkage can lead to the formation of internal cracks, resulting in tensile stress. The fibers within the cementitious composite not only resist this tensile stress but also help reduce stress concentration at crack tips, thereby preventing crack propagation and the merging of smaller cracks into larger ones [Al-Ghazali et al., 2022].

Hanizam et al. (2013) conducted a study on the mechanical performance of kenaf fiber-reinforced foamed concrete containing 0.25% and 0.40% kenaf fiber by weight. The composites were evaluated for compressive strength, flexural strength, and water absorption characteristics. The results showed an increase in flexural strength by 61% and 78% for the 0.25% and 0.40% fiber contents, respectively. In the study by Chaitanya et al. (2022), concrete was partially modified by replacing cement with bamboo leaf ash and incorporating kenaf fibers. The experimental results showed that the addition of 1% kenaf fiber resulted in compressive strengths of 29.07 N/mm² at 7 days and 41.47 N/mm² at 28 days. Similarly, the split tensile strengths at 7 and 28 days were 3.11 N/mm² and 4.22 N/mm², respectively. The findings indicated that the addition of kenaf fiber had a greater positive impact on concrete strength compared to bamboo leaf ash.

4.0 RESEARCH GAP IN THE DURABILITY PROPERTIES OF KENAF FIBER-REINFORCED CEMENTITIOUS COMPOSITES

Although the use of kenaf fiber in cementitious composites has shown encouraging results in improving mechanical performance, the durability aspects of these composites remain inadequately addressed in current literature (Rahman et al., 2021; Zainudin et al., 2023). This presents a significant research gap, especially considering the potential application of kenaf fiber-reinforced composites in structural and infrastructure settings exposed to aggressive environmental conditions. A primary concern is the inherent hydrophilicity of kenaf fiber, which makes it susceptible to moisture absorption, dimensional instability, and microbial attack. These issues can degrade the fiber–matrix interface over time, adversely affecting the long-term structural integrity of the composite (Ismail et al., 2020). While chemical modifications such as alkali, silane, or acetylation treatments have been investigated to improve durability by reducing water uptake and enhancing fiber–matrix adhesion, systematic evaluations of how these treatments influence long-term durability metrics are still lacking (Liew et al., 2022). Moreover, most existing durability studies focus on short-term laboratory-scale tests under controlled conditions, which may not accurately simulate real-life environmental exposures, such as wet–dry cycles, freeze–thaw actions, carbonation, sulfate and chloride penetration, or biological degradation (Roslan et al., 2021; Chong et al., 2023). Additionally, there is limited understanding of how fiber parameters such as content, length, orientation, and distribution affect durability performance. Recent studies have begun exploring these factors, but comprehensive, long-term research that integrates these variables within realistic environmental scenarios is still needed (Mahmood et al., 2025). In light of growing interest in sustainable and green construction materials, closing this research gap is essential to validate the long-term applicability, resilience, and environmental performance of kenaf fiber-reinforced cementitious composites.

5.0 CONCLUSION AND RECOMMENDATIONS

Overall, kenaf fiber-reinforced cement composites offer a compelling range of advantages, making them a promising material for sustainable construction. Their enhanced mechanical properties, lightweight nature, environmental benefits, cost-effectiveness, improved thermal and acoustic insulation, and versatility position them as a viable alternative to traditional materials. As the construction industry increasingly prioritizes sustainability and innovation, kenaf fiber-reinforced cement composites are poised to play a key role in advancing eco-friendly building practices.

The consumption of kenaf fiber scientifically proved that it promoted significant advantages in cementitious composites. This can lead to sustainable construction and avoid continuously relying on synthetic fibers, which are high in materials and processing costs. Although this review presents only a limited number of findings on the performance of kenaf fiber in cement composites, the observed properties suggest that kenaf fiber holds promise for applications such as road pavements, slabs, and other similar construction elements. In the long term, further research is essential to explore and highlight the full potential of kenaf fiber. Looking ahead, the development of hybrid cementitious composites combining kenaf with synthetic fibers could offer a promising approach to optimizing both performance and sustainability in future construction practices.

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